Report as of FY2011 for 2011PA156B: "Quantifying the Nitrogen Retention Capacity of Legacy Sediments and Hydric Soils Before and After Restoration"

Publications

Project 2011PA156B has resulted in no reported publications as of FY2011.

Report Follows

Pennsylvania Water Resources Research Center
FY2011 Final Report

PROJECT TITLE AND PRINCIPAL INVESTIGATORS

Quantifying the nitrogen retention capacity of legacy sediments and hydric soils before and after restoration

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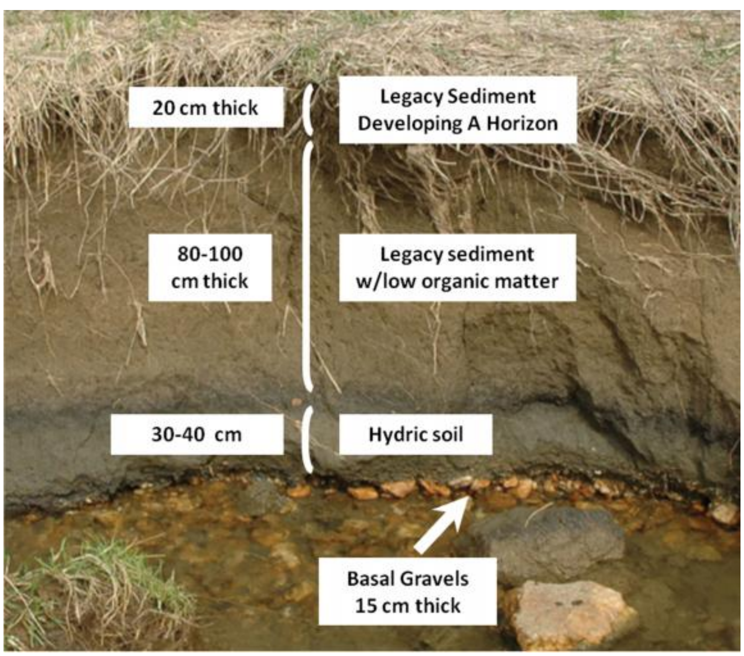
STATEMENT OF WATER PROBLEM: The water problem that this proposal focuses on is eutrophication, and specifically how regionally prevalent legacy sediments alter the transfer of NO_3^- from soils to streams. We use our research site, Big Spring Run (BSR), as the case for describing the nature of the problem. As in many stream banks of the mid-Atlantic Piedmont region, the stream banks along BSR consist of four principle stratigraphic units (Fig. 1), which from bottom to top include: (1) basal gravels; (2) pre-settlement hydric soils; (3) post-settlement alluvium and colluvium (the latter informally called "Legacy Sediments"); and (4) newly developing A horizon (Walter and Merritts, 2008). The basal gravels, are composed of angular to subangular quartz cobbles, which are interpreted to derive from Pleistocene periglacial lag deposits. These gravels are overlain by a 30-40 cm dark, organic-matter-rich hydric soil, which apparently formed in a fluvial wetland environment over the last 10,000 years (Merritts, et al., 2005; Walter and Merritts, 2008). Legacy sediments were deposited on top of the hydric layer during the historic, post-settlement period marked by deforestation, land clearing, and plowing of uplands and valley slopes. This period of accelerated soil erosion coincided with the construction of numerous milldams in the mid-Atlantic. Dams created reservoirs that flooded valley bottoms and acted as efficient sediment retention ponds. Behind the former milldam on BSR, a gradient of legacy sediment depth now exists with sediments thickest near the location of the dam, and tapering off upstream away from the dam. In the top 20 cm of the legacy sediment, an organic-matter-rich A horizon is developing (Fig. 1). Beneath the A



horizon, and continuing down to the surface of the hydric layer is a ~80-100 cm thick layer of legacy sediment with lower organic matter content (relative to the A horizon above and hydric below).

Legacy sediments introduce two key problems for water quality. First, stream bank erosion is a significant non-point source of sediment that can impair downstream waterways (Trimble 1997) and in the mid-Atlantic, legacy sediments constitute a substantial volume of sediment stored in stream corridors. Lancaster County is recognized as a hotspot for high sediment and nutrient yields to the Chesapeake Bay, and bank erosion of legacy sediments is a major source of these pollutants (Merritts and Walter, 2003). Second, legacy sediments alter flowpaths for water and dissolved nutrients from uplands to streams. At BSR, trees planted to improve riparian function have all died, suggesting that traditional riparian zone BMPs may fail on legacy sediments. Given their prevalence in PA, there is a critical need to understand how N flows through legacy sediments to improve predictions and management of N transport from uplands to streams. We propose to fill that need by assessing NO_3^- retention in BSR sediment.

A portion of BSR (Fig. 2) has been proposed by the Pennsylvania Department of Environmental Protection (PA-DEP) as a test site for implementing and monitoring a new "floodplain and wetland restoration" Best Management Practice (BMP) (Hartranft, 2007). BSR was selected because of the well-defined legacy sediment accumulation, because it is in a rural setting experiencing little land-use change, and because it was already a site for which much baseline data had been obtained (Legacy Sediment Workgroup, 2006). Previous studies have shown that the geomorphic stability of restored streams may be improved after restoration (Mayer et al., 2009). Restored sites transport less sediment and halt the lateral migration of the streams. Based on these findings, the proposed BMP seeks to re-establish the natural function and condition of the stream, wetland, floodplain, and riparian zones within the site.

In July of 2011, legacy sediments will be removed throughout a portion of the BSR watershed, which will expose the buried wetlands and reconnect the original floodplain hydrology of the site. This restoration effort represents a unique opportunity to assess the effects of watershed restoration on ecological function. The identification of BMPs to mitigate the impacts of legacy sediments on streams and wetlands is an important goal for resource managers in the Mid-Atlantic region (Mayer and Forshay, 2009).

NATURE, SCOPE, and OBJECTIVES: We have noted that legacy sediments affect water quality in two ways: 1) by direct inputs of sediment into streams, and 2) by affecting the transfer of dissolved nutrients from soils to streams. The scope of this proposal involves #2; we seek to quantify the effects of legacy sediment on the transfer of nutrients from soils to streams at one site in PA. Our research site is a reach within BSR because the extensive background information and scheduled restoration make this site ideal for testing our three **__hypotheses__**:

Hypothesis 1: Prior to restoration, three soil layers that are typical of legacy sediment areas (surface legacy sediment enriched in organic matter, subsurface legacy sediment low in organic matter, and buried hydric soil) will differ in their ability to remove NO_3^- from soil solutions.
Rationale for Hypothesis 1: We expect that differences in organic matter content and microbial activity among these layers will lead to large differences in NO_3^- retention. If soil layers vary in NO_3^- retention then it follows that different hydrologic flowpaths will lead to different efficacy of NO_3^- filtering as upland N moves to streams. Monitoring at the site has revealed four potentially important flowpaths: 1) saturation from the surface downward (from heavy local rain), 2) saturation from the hydric soil upward (from rising water tables), 3) lateral flow through the hydric layer only (as water moves along the soil-bedrock interface from uplands into the sediment), and 4) lateral flow through the hydric layer plus subsurface legacy sediment (same as 3, but with a greater soil volume saturated). We will test Hypothesis 1 by extracting intact soil columns that include the three soil layers of interest and then experimentally manipulating the flow of isotopically labeled nitrate ($^{15}NO_3^-$) to mimic these 4 flowpaths.

Hypothesis 2: Drought followed by rewetting will cause variations in NO_3^- flushing from the different layers.
Rationale for Hypothesis 2: Studies at several scales have shown that drought leads to pulses of NO_3^- that can impact water quality. A regional scale synthesis has shown high NO_3^- following drought in streams throughout the mid-Atlantic (Kaushal et al., 2010). Research by a Ph.D. student of the PI has shown that in a small catchment in Maryland, a pulse of NO_3^- moves from surface soils to subsoils following drought. Finally, our own preliminary data from BSR (described below) show that soil drying induces a large pulse of NO_3^- in surface soils. Our column studies will build on these preliminary data by assessing whether drought-induced NO_3^- pulses in surface soils are flushed to deeper layers, and how/if they are retained in other layers. We will test Hypothesis 2 by allowing the soil columns described above (for testing Hypothesis 1) to dry, and then rewetting them with N-free water. The pulse of $^{15}NO_3^-$ that occurs following rewetting will reveal flowpaths likely to carry NO_3^- rich water to streams following drought.

Hypothesis 3: Following restoration, the previously buried hydric layer will increase its NO_3^- retention capacity (relative to the pre-restoration hydric layer).
Rationale for Hypothesis 3: State (PA-DEP) and federal (EPA) agencies are interested in testing the efficacy of legacy sediment restoration as a BMP for improving water quality. Restoration removes legacy sediment to expose the buried hydric layer. We will test Hypothesis 3 by removing legacy sediment and then immediately extracting an intact core of the entire hydric layer. We will pass $^{15}NO_3^-$ through the hydric layer and by comparing results to those from columns used to test Hypothesis 1, we can quantify changes in hydric layer NO_3^- retention that occur when legacy sediments are removed. These experiments will provide preliminary data to assess how newly exposed hydric layers may retain NO_3^- following restoration.

These hypotheses contrast the dominant geomorphic (soil layers), climatic (drought), and cultural (restoration) sources of variation in NO_3^- retention capacity in legacy sediment and buried hydric soils. We propose to test these hypotheses using large soil columns that are engineered to allow experimental flowpath manipulations and $^{15}NO_3^-$ additions.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Significance: Legacy sediments were deposited during the historic, post-settlement period due to intense land clearing, deforestation, and the construction of numerous milldams. These dams occur in high concentrations in the mid-Atlantic region, and constitute substantial volumes of sediment stored in stream corridors. Legacy sediments introduce two key problems for water quality. First, streambank erosion is a significant non-point source of sediment that can impair downstream waterways (Trimble, 1997). Second, legacy sediments alter flowpaths for water and dissolved nutrients from uplands to streams. Understanding how uplands and legacy sediment accumulation zones act to remove N before entering streamwaters is important in predicting downstream effects of legacy sediments. To investigate the fate of N as it moves across the landscape and through the soil profile laboratory studies were conducted on intact soil cores collected from Big Spring Run (BSR) in Lancaster, Pennsylvania. This site at BSR has acted as an infrastructure for research and education because a growing group of researchers, students, and stakeholders are focusing efforts on this watershed as a primary case study in science-based legacy sediment remediation via stream restoration.

Lancaster County, where BSR is located, is recognized as a hotspot for high sediment and nutrient yields to the Chesapeake Bay, and bank erosion of legacy sediments is a major source of these pollutants (Merritts and Walter, 2003). As in many streambanks of the mid-Atlantic Piedmont region, the streambanks along BSR consist of three principle stratigraphic units, which from bottom to top are: (1) pre-settlement hydric soils, which formed in a fluvial wetland environment that persisted for over 10,000 years prior to settlement; 2) post-settlement alluvium and colluvium (the latter informally called “Legacy Sediments”); and (3) newly developed A horizons, which are also classified as legacy sediments (Merritts and Walter, 2003; Merritts et al., 2005; Walter and Merritts, 2008).

Principal Findings: We are still in the data analysis phase of this project, so here we report key progress to date, rather than a major synthesis of key findings. We first extracted intact soil columns from Big Spring Run (BSR) that extended from the surface soil into the legacy sediment and down to the basal gravels that existed below the buried hydric layer. However, due to excessive compaction, we altered our sampling scheme. Instead, intact soil columns were extracted for each of the 3 significant soil layers at BSR (surface, legacy, and hydric). Isotopically labeled nitrate ($^{15}NO_3^-$) was added to each column to quantify NO_3^- retention in the different soil layers. Following the addition of the isotopically labeled solution the columns were allowed to dry for a month and then rewet with N-free water in order to quantify the drought-induced loss of $^{15}NO_3^-$ each layer. These experiments allowed the quantification of changes in nitrogen (N) in each separate soil layer, which will provide critical information for 1) assessing sources and sinks of N along streams impacted by legacy sediments, 2) improving the efficacy of riparian buffers on legacy sediments, and 3) understanding the effects of past land use on contemporary N flow from soils to streams.

Our specific **activities** (and their timeline) were:
May 2011: Purchased PVC and fabricated columns.
June 2011: First attempt at extracting soil columns from BSR – lots of compaction, so had to rethink sampling procedure.

July 2011: Successful extraction of soil columns from BSR – cores of each separate layer, as opposed to one core containing all layers; brought them to PSU. Inserted moisture/temperature probes into each core.
November/December 2011: Traced the fate of $^{15}NO_3^-$ through the columns before drought.
January 2012: Traced the fate of $^{15}NO_3^-$ through the columns upon rewetting after drought.
Measured concentrations of NO_3^- and NH_4^+ in leachates and soil extracts.
February 2012: Prepared soil and water samples for ^{15}N analysis.
March 2012: Solid samples sent to Boston University for ^{15}N analysis, and liquid samples sent to U.C. Davis for ^{15}N analysis.
April 2012: Received ^{15}N data from U.C. Davis.
May 2012: Received ^{15}N data from Boston University. Data analysis started.
Projected for the future – June/July 2012: Write manuscript.

STUDENTS & POSTDOCS SUPPORTED: Graduate Student – Julie Weitzman, Soil Science & Biogeochemistry Dual Degree, Ph.D.; Undergraduate Student – Lena Harper, Environmental Resource Management, B.S.; Undergraduate Student – Marian Kochin, Environmental Resource Management, B.S.; Undergraduate Student – Tom Bassett, Environmental Resource Management, B.S.

PUBLICATIONS: None to date.

PHOTOS OF PROJECT


Walmart
Legacy A
Hydric #4